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October 19, 1993

William F. Caton
Acting Secretary
Federal Communications Commission
Room 222 -- Mail Stop 1170
1919 M Street, N.W.
Washington, D.C. 20554

Re: Ex Parte Communication in
PR Docket No. 93-61

Dear Mr. Caton:

Pursuant to Section 1.1206(a)(2) of the Commission's Rules, I am filing the original and one copy of this letter to report an ex parte communication in the above-referenced proceeding.

Today, on behalf of Southwestern Bell Mobile Systems, Inc. ("SBMS"), Louis Gurman of this office and the undersigned met with Mr. Byron F. Marchant, Legal Advisor to Commissioner Andrew C. Barrett, to discuss the views that SBMS expressed in the Reply Comments it filed in this proceeding. A research proposal that has been prepared by the Mobile and Portable Radio Research Group ("MPRG") of Virginia Tech to study the capacity and interference resistance of spread spectrum automatic vehicle monitoring systems in the 902-928 MHz band was also discussed. Enclosed is a copy of the proposal that was provided to Mr. Marchant.

Please call me if you have any questions regarding this notice.

Respectfully submitted,

Robert L. Hoggarth

Robert L. Hoggarth

Enclosure

cc (w/o enclosure):
Byron F. Marchant

Capacity and Interference Resistance of Spread-Spectrum Automatic Vehicle Monitoring Systems in the 902-928 MHz ISM Band

a research proposal

submitted to

Mr. Jonathon Rizzo
Southwestern Bell Mobile Systems
18111 Preston Road, Suite 900
Dallas, TX 75252

by

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September 3, 1993

1. Introduction and Problem Statement

Innovations in wireless technology have enabled the rapid growth of a large range of mobile communications services. Although cellular telephone service and the forthcoming personal communications service have attracted the widest attention, a broad range of more specialized services are also becoming commercially viable. Automatic Vehicle Monitoring (AVM) is one such service. AVM systems might typically offer the following services:

- Fleet Management. Dispatch, routing, and position location of large fleets of vehicles within a metropolitan area. This could include taxis, delivery vehicles and service trucks.
- Vehicle Security. Tracking and location of stolen vehicles. Enabling and disabling of vehicle security alarms.
- Emergency Services. Notification and position location of roadside emergencies. Routing of service vehicles to the emergency location.
- Messaging. Transmission of alphanumeric and voice messages to vehicles within a metropolitan area.

Several companies are in the process of developing and deploying AVM systems. These companies include:

- MobileVision of Indianapolis, IN
- North American Teletrac of Walnut Creak, CA
- Pinpoint Communications of Richardson, TX
- Southwestern Bell Mobile Systems of Dallas, TX

Each of these AVM systems is designed to operate in the 902-928 MHz ISM band. Although implementation details vary between systems, they share several common technical features. Each employs a set of narrowband (25 to 50 kHz) channels for the forward link from the base station to the mobile. This forward link carries control, status and group and individual messaging information. The reverse link from the mobile to the base station employs a wideband direct-sequence spread-spectrum (DS/SS) signal. The characteristics of this DS/SS signal vary widely between systems. Southwestern Bell claims their system requires a 2 MHz bandwidth, while MobileVision and Teletrac claim their systems require 8 MHz bandwidth and Poinpoint has proposed a 26 MHz bandwidth system. The majority of these systems allow multiple access along the reverse link using Code Division Multiple Access (CDMA) techniques, although the Southwestern Bell system uses a combination of CDMA and Frequency Division Multiple Access (FDMA). All systems employ triangulation on the DS/SS signal for position location.

The Federal Communications Commission (FCC) has indicated its intention to create rules which foster creative use of Specialized Mobile Radio (SMR) Service such as AVM. In one recently proposed rule (NPRM 93-144), the FCC proposed the consolidation of channel allocations for private land mobile radio stations in the 800 MHz band to metropolitan service areas (MSA) or even larger areas. In another proposed rule (NPRM 93-61), the FCC proposed guidelines for AVM service within the 902-928 MHz ISM bands.

While agreement among commenters can be found on many issues, spectrum sharing remains a significant point of contention. System developers that currently have licenses to commercially operate an AVM system have proclaimed that spectrum sharing is not possible between AVM system providers. System developers who do not currently have licenses have taken a more positive view towards spectrum sharing. In addition to interference between AVM systems, there exist concerns over potential interference with part 15 devices, also operating in the 902-928 MHz ISM band.

Several studies have addressed portions of the interference problem. However, each of the studies to date has limitations. Each of the studies has been carried out by consultants to one of the AVM service providers, with little or no opportunity for participation from competing service providers. Furthermore, each of the studies has been primarily theoretical in nature. As a result, the studies do not reflect many of the important characteristics of the mobile communications channel at these frequency bands, such as multipath propagation and impulsive noise. Neither do these studies take into account the characteristics of real-world communication systems, including nonlinearities and intermodulation products. As a result, questions remain about the effects of interference between systems.

The Mobile and Portable Radio Research Group (MPRG) at Virginia Tech has substantial experience and expertise in modeling the propagation characteristics of the mobile communications channel. The MPRG also has expertise in the performance evaluation of communication systems and the development of interference rejection techniques. We propose to undertake a study of the effects of interference on the performance of AVM systems. The purpose of this study will be to determine the feasibility of spectrum sharing in AVM bands and to determine possible techniques to mitigate potential interference problems. We believe that this study will be useful to the FCC in formulating rules for issuing AVM licenses.

It is the intention of the MPRG to satisfy two major criteria in carrying out this study:

- Independence. The MPRG's status as an independent academic organization with a broad range of industrial support will allow for considerable autonomy in carrying out the study. Southwestern Bell has already committed to provide technical and financial support of this study. Each of the other major AVM services providers will be invited to participate both financially and technically. Results of the study will be review by members of Rutger's WINLAB, a second independent academic organization.
- Technical detail. The investigation will combine theoretical analysis with the study of the real-world phenomena. MPRG has significant expertise in modeling the mobile radio communications channel. The study will include the effects of multipath propagation, Doppler characteristics and impulsive noise. The final conclusions will reflect both practical and academic considerations.

The remainder of this proposal is organized into four sections. Section 2 provides a detailed statement of work for the proposed study. The study is divided into four phases. Phase 1, will investigate the relationships between capacity and bandwidth requirements for an AVM system, taking into account realistic channel conditions. This phase will require approximately 9 months. Based on the outcome of Phase 1, three additional phases of work may be carried out. These additional phases are also described. Section 3 enumerates the deliverables of this contract. The principal deliverable at the end of the study will be a report discussing the feasibility of spectrum sharing under real world conditions. Section 4 will provide a discussion of MPRG research capabilities and expertise. Finally, Section 5 will discuss management of the proposed research.

2. Statement of Work

We propose a four phase study to investigate the issues of spectrum sharing and interference for AVM systems operating in the 902-928 MHz frequency bands. Phase 1 will develop tradeoffs between system performance and bandwidth, while taking into account realistic channel conditions. Phase 1 will require approximately nine months to complete, and is described in detail below.

Based on the outcome of Phase 1, three additional phases of the project may be pursued. Phase 2 would be to investigate alternative techniques for spectrum sharing between AVM systems. Phase 3 would consist of detailed evaluation of the major proposed standards for AVM operation. Phase 4 would include actual measurement of the interference resistance of the major AVM technologies. These three phases would proceed in parallel and require a total of ten months after completion of Phase 1. At the present time, only Phase 1 is being proposed. Brief descriptions of additional phases are included to indicate the direction in which the research could proceed.

Phase 1 - Performance Analysis of AVM Systems under Real-World Conditions

Phase 1 will consist of a detailed performance analysis of AVM systems under real-world conditions. The goal of this study will be to develop general relationships between capacity, power and bandwidth requirements of AVM systems. We will determine how these relationships are effected by realistic propagation, noise and interference characteristics, and by practical limitations of communication systems. This information will be useful to the FCC in determining policies on spectrum allocation for AVM systems. We will carry out this work in several tasks.

Task A - Definition of a Baseline AVM System

We will begin by defining a baseline AVM system for analysis. Although each of the candidate AVM technologies contains some unique features, they share a broad range of characteristics. Since there is general agreement that the narrowband channels for the forward link should be allocated on an exclusive basis, and since the DS/SS signals on the reverse link have much higher spectral occupancy requirements, our analysis will focus mainly on the reverse link. The goal will be to define a simple DS/SS system model which reflects the important characteristics of the principal AVM technologies, and allows us to investigate the effects of bandwidth, power, and spectral shaping on system performance. The system will employ a CDMA multiple access technique. This task will be completed within one month.

Task B - Theoretical Baseline Analysis

Our next task will be to carry out a baseline analytical study of the performance of a DS/SS system. Using accepted analysis techniques, we will study the relationship between capacity, range, power, noise and bandwidth for our baseline system model. The MPRG has significant experience in the analysis of CDMA systems. The goal of this task is to develop a baseline performance standard for comparison with performance under realistic conditions later in the study. This task will be completed within two months.

Task C - Analysis of RF Propagation Effects

Beginning with task C, we will consider the effects of real world factors on the performance of AVM systems. The RF propagation characteristics of interest include the effects of multipath propagation and Doppler. One principal benefit of spread-spectrum systems is the ability to reject multipath interference. As a result, one key question is what choice of bandwidth is required to achieve multipath rejection. Another important question is the effect of vehicle speed on system performance.

We will evaluate the performance of our candidate DS/SS AVM system under propagation characteristics which are typical of both urban and suburban mobile environments. We will investigate vehicle speeds in ranging from 0 to 100 km/hour. We will employ both analytic and simulation techniques as appropriate.

The MPRG has substantial experience in propagation measurement and modeling for the mobile radio channel. The MPRG has conducted extensive measurement campaigns to collect data on the power delay profiles of such channels. Based on these measurement campaigns, the MPRG has developed the statistical channel model SMRCIM (Simulation of Mobile Radio Channel Impulse Response) which is widely used.

The MPRG has also developed tools for the simulation of DS/SS system under realistic channel conditions. The Bit Error Rate SIMulator (BERSIM) developed by MPRG is capable of importing channel models from SMRCIM and simulating mobile communication system performance under realistic channel conditions. BERSIM has been extended to include models of DS/SS systems. The MPRG has also developed analytic models for evaluating the performance of DS/SS systems under realistic channel conditions.

Task C will be completed within six months.

Task D - Evaluation of Interference Effects

In addition to the effects of RF channels, the performance of practical AVM systems will be limited by the effects of interference. Many types of interference are possible, including multiple access interference within a single AVM system, interference between multiple AVM systems, interference from impulse noise sources, and interference between AVM systems and part 15 systems operating in the ISM band. We will consider each of these.

The MRPG has developed analytic and simulation tools to evaluate the performance of DS/SS systems in multiple access interference. These allow for analysis of the effects of imperfect power contro and for interference from other users operating in adjacent cells. Note that while power control may be possible within a single cell system, it will not be possible in general to eliminate the near/far problem for the triangulation of the DS/SS signal which must take place at three separate cell sites.

Interference from impulse noise sources is also a significant problem. The MPRG has undertaken a study of impulsive noise in the 902-928 MHz bands. We will use the results of this study to evaluate the effects of impulsive noise on the AVM system.

Finally, we will evaluate the potential for interference between part 15 users and AVM systems. We will proceed by developing a simple model for a spread-spectrum part 15 device and evaluate the interference effects on both the part 15 and the AVM systems for multiple cases of range and power levels. The effects on AVM system capacity will also be investigated.

This task will proceed in parallel with Task C and will be completed within six months.

Task E - Limitations of Practical RF Systems

We will analyze the effects of practical implementation limitations within DS/SS systems. Among the effects we will consider are nonlinearities within amplifiers, intermodulation products generated within the receiver, limitations of spectral shaping characteristics of filters, and the ability of filters to reject adjacent channel interference. We will develop an estimate of the effect of these limitations on the AVM system capacity. We will also suggest basic design rules to address these limitations. Task E will be completed within seven months.

Task F - Description of Candidate Spectrum Sharing Techniques

We will develop a list of possible spectrum sharing techniques for AVM systems. These techniques might include overlay of AVM systems using CDMA, adjacent channel location of AVM systems (possibly locating the main lobe of one system over a sidelobe of a second system, spectral shaping, and advanced DSP techniques for interference rejection. We will qualitatively describe the benefits and disadvantages for each of the enumerated techniques. Task F will be completed within eight months.

Task G - Evaluation Documentation of Results

The results of this study will be documented in a final report. The report will contain results describing the relationships between capacity, bandwidth, power, noise and interference under realistic conditions. The report will also describe the implications of these results for future FCC guidelines, and will contain an assessment of areas requiring further study. Finally, the report will describe possible techniques for minimizing interference between AVM systems. All results will be evaluated by an independent consultant. Task G will be completed within nine months.

Phase 2 - Spectrum Sharing Techniques for Multiple AVM Systems

In Phase 2, we will investigate and compare spectral sharing techniques for multiple AVM systems. We will begin with the spectral sharing techniques described in Task F of Phase 1. In Phase 2, we will investigate these techniques quantitatively using the real-world models constructed for Phase 1. Promising spectral sharing techniques include spectral shaping for signal located on adjacent channels and advanced DSP techniques for interference rejection. Based on the results of our investigation, we will formulate recommendations for spectrum sharing planning. Phase 2 will require approximately 10 months to complete.

Phase 3 - Evaluation of Candidate AVM Technologies

In Phase 3, we will examine each of the possible AVM technologies in detail. At a minimum, this will include technologies employed by: MobileVision, North American Teletrac, Pinpoint Communications, and Southwestern Bell Mobile Systems. We will obtain documentation on each system and carefully evaluate the merits of each systems. Particular attention will be paid to the capacity, spectrum requirements and interference rejection capabilities of each system. We will prepare a report describing the compatibility of each of the candidate technologies. Phase 3 will require approximately 10 months and may proceed in parallel with Phase 2.

Phase 4 - Measurement of Noise and Interference Rejection Capabilities

Phase 4 of this project will evaluate candidate AVM technologies. We will acquire working prototypes of all AVM systems and subject them to field testing. We will design tests to evaluate the noise resistance and interference rejection capability of each system. All major AVM service providers will be given an opportunity to participate. We will conduct these tests jointly with each of the participating companies. Phase 4 will require approximately 12 months and may proceed in parallel with Phases 2 and 3.

3. Deliverables

The primary deliverable of this project will be a report describing the relationships between capacity, bandwidth, noise and interference for a practical AVM system based on DS/SS technology. This report will be completed within nine months. The MPRG will carry out the research independently of any particular service provider.

The final report will describe:

- The relationship between bandwidth, power, noise and capacity for a multiple cell DS/SS system.
- The effect of multipath propagation on AVM system performance for urban environments and for different system bandwidths.
- The effect of Doppler on system performance for vehicle speeds ranging from 0 to 100 km/hour.
- The effect of co-channel and adjacent channel interference on AVM system performance.
- The effect of impulse noise on AVM system performance.
- The interference between AVM and part 15 systems and the anticipated effect on performance.
- The limitations of practical RF systems and the effect of these limitations on system performance.
- Possible techniques for spectrum sharing between multiple AVM systems.
- Preliminary recommendations for FCC allocation of spectrum.

4. MPRG Research Capabilities

The MPRG has significant research expertise in the areas of spread-spectrum systems, mobile radio propagation and interference rejection techniques. As a result, the MPRG possesses a combination of facilities and experience which is uniquely suited to addressing the problem of spectrum sharing within AVM systems.

In this section we describe the research capabilities of the MPRG. First we describe the general research capabilities of the MPRG. Next, we describe the specific research expertise in the MPRG which is applicable to the work described in this proposal. Finally, we include brief biographies of the three principle investigators for this project.

A. MPRG Research Facilities

The Bradley Department of Electrical Engineering

The Mobile and Portable Radio Research Group (MPRG) is a part of The Bradley Department of Electrical Engineering, one of the largest electrical engineering departments in the nation, with 60 full-time faculty members, and a broad range of graduate research and study programs. The Department produces approximately 250 bachelor's degrees each year, and is consistently ranked in the top 20 programs. Virginia Tech is one of the few universities that offers courses in mobile and portable radio as a regular part of the curriculum. The Bradley Department of Electrical Engineering conducts about 130 research projects each year with an annual research budget of approximately ten million dollars. The Department has approximately 550 graduate students in electrical engineering.

The Mobile and Portable Radio Research Group

The MPRG was founded in 1990 to conduct research in emerging wireless communication technologies. The group has research, teaching and service missions which are national in scope, and is a leading producer of professionals for the wireless communication industry. The group consists of three full-time faculty, three support staff and approximately thirty graduate students. Major MPRG research thrusts include:

- Measurement and analysis of propagation characteristics for wireless channels.
- Site-specific prediction of propagation characteristics.
- Simulation and analysis of wireless communications systems using real-world channel models.
- Development of signal processing algorithms for interference rejection, antenna steering, error correction and fast synchronization.

Since its inception, the MPRG has conducted over $2.6 million in funded research. Core funding is provided by the MPRG Industrial Affiliates Foundation, a coalition of 14 major corporations in the wireless field. MPRG Industrial Affiliates include: Apple Computer, AT&T, Bell Communications Research (BellCore), BellSouth, BNR, Ericsson-GE Mobile Communications, The Federal Bureau of Investigation (FBI), Grayson Electronics, GTE, MCI, Motorola, Rockwell, Southwestern Bell, Telisys Technologies Laboratory, and US West. The MPRG prepares quarterly research reports for its industrial affiliates members and promotes aggressive technology transfer through frequent visitation. Most industrial affiliate members have hired one or more MPRG graduates.

The MPRG also conducts specific funded research for individual sponsors. Currently, 14 organizations sponsor funded research with the MPRG, including the Advanced Research Projects Agency (ARPA). Within the last year, MPRG has received two prestigious awards from the National Science Foundation: a Presidential Faculty Fellowship, and a Research Initiation Award.

Research Facilities

The MPRG possesses outstanding facilities for computing, RF measurement, and DSP algorithm development. The MPRG operates a network of 12 SUN SPARC 10 workstations with access to INTERNET and a larger departmental network. The MPRG's facilities for wireless propagation measurement are among the best available at any academic facility. MPRG researchers have applied for three patents based on measurement work. The current generation of propagation measurement equipment was constructed entirely by MPRG researchers. The system employs a spread-spectrum sliding correlator receiver for measurement of the channel power delay profile. The system features:

- 4 nanosecond time resolution.
- Measurement frequencies ranging from 100 MHz to 25 GHz.
- Disk storage of measured data for further analysis, and spectrum analyzer and oscilloscopes for immediate frequency and time domain analysis of measured data.

MPRG Software Tools

MPRG researchers have access to tools for technical word processing (Framemaker), plotting (PVWAVE), software development (C and C++), and signal processing (Xmath and Matlab). In addition, MPRG researchers have developed several software packages for wireless communication research. These products are made available to the wireless community through Virginia Tech's intellectual properties division. Over 100 copies of MPRG software are now in use in academic and industrial research labs including SIRCIM, SMRCIM, and BERSIM, described in Section III B.

MPRG Outreach and Technology Transfer

The MPRG works to aggressively transfer knowledge to industry, and develop new products and services. All research results are disseminated to industrial affiliates through quarterly mailings of research reports. In addition, the MPRG newsletter *The Propagator* reaches an audience of over 4000. The MPRG holds an annual research symposium on wireless and personal communications. The third and most recent, held in June 1993, featured twenty one high quality research papers and was attended by over 150 wireless professionals. The proceedings from this symposium will be published in book form by Kluwer Academic Publishing.

B. Research In Mobile Spread-Spectrum Systems

In recent years, the MPRG has been an active contributor of research in areas with direct application to proposed AVM systems. This include: measurement, simulation and prediction of the mobile communications channel; analysis and simulation of spread-spectrum systems; and research into advanced techniques for interference rejection.

Research in Radio Wave Propagation

Dr. Rappaport founded the MPRG in 1990 and has advised sixteen M.S. and Ph.D. students in the areas of RF propagation, antenna design, signal processing, and capacity analysis. He and his graduate students have developed the first channel modeling software packages (SIRSIM, BERSIM, SMRSIM) for indoor and urban mobile communication systems. He currently serves as PI on a DARPA project which is developing site specific

RF prediction tools that incorporate terrain, building locations, and physical propagation paths. Such information is vital to the analysis, simulation, and design of AVM systems. Sophisticated and realistic channel modeling tools are being created specifically for allowing accurate assessments of the performance of adaptive arrays [Sch92b, Sei93, Tra93, Ho93]. His current research includes the development of novel antenna structures and adaptive array algorithms that will demonstrate the accuracy of the simulation and analysis tools.

Research in Direct-Sequence Spread-Spectrum

Dr. Woerner's research has focused on design and evaluation of DS/SS systems for wireless communications. His most important accomplishments have been in pioneering the use of trellis-coded modulation techniques for spread-spectrum communications, and the development of analysis and simulation tools for the evaluation of DS/SS systems.

Dr. Woerner has actively developed analysis and simulation techniques for the evaluation of CDMA systems in real-world environments. Traditionally, analysis of DS/SS systems has relied heavily on approximating all interference as Gaussian. This approximation may not be valid at low bit error rates or in the case of sever near/far problems. Lehnert and Pursley have developed techniques to accurately analyze the effects of multiple access interference and obtain tight performance bounds [Leh87, Leh89]. Dr. Woerner has extended these results to systems with soft decision [Woe92b] and hard decision error correction codes [Woe93c], systems with imperfect power control [Woe92a], and systems with real world multipath channels and RAKE receivers [Cam93a, Cam93b].

Dr. Woerner has also worked on the development of simulation tools which model complex DS/SS systems and channels. The MPRG has developed a Bit Error Rate SIMulator (BERSIM) [Rap91, Tho92], which has been extended to model the IS-95 CDMA cellular standard [Li93a, Li93b]. BERSIM has several advantageous characteristics which include its modular construction that allows the addition of new modules, use of a wide variety of channel impulse response models, and the ability to record bit-by-bit error patterns, which allows for assessment of the effects of burst error events on actual transmitted data.

Research in Interference Rejection

Dr. Reed's research has focused on the use of advanced DSP techniques for interference rejection. Linear time dependent adaptive filters were first demonstrated by [Fer81] and later shown by Dr. Reed and graduate students to be very effective in reducing co-channel interference for a variety of non-spread spectrum signals [Ree90a,b, Ree88, Men88, Men89, Men91, Ree87, Ree91, Ree92]. Reed in his Ph.D. dissertation introduced new time-dependent adaptive filtering algorithms for interference rejection, including frequency domain algorithms and blind time-domain algorithms [Ree87]. He also showed the theoretical performance of time-dependent adaptive filters for specific test cases [Ree87, Ree90a, Ree90b]. The first application of time-dependent filtering for enhancing and despreading spread spectrum for reconnaissance applications was proposed in [Ree89].

Several blind algorithms have been developed for time-dependent adaptive filters. The first of these algorithms, the spectral correlation discriminator (SCD), uses a frequency-shifted or conjugated version of the input signal as the training signal [Ree88]. This technique is easily combined with other adaptive techniques to improve performance [Men89, Men91]. Personal experience has shown phase modulated signals corrupted by television interference can be recovered using the SCD compounded with a CMA TDAF when the

SIR is as low as -19 dB. This mixture of time-dependent filtering operations, beginning with robust blind techniques and followed by less robust, but better performing blind TDAF techniques.

Most of the previous work in time-dependent filtering has focused on applying these techniques to reconnaissance applications of non-spectrally efficient signals. Commercial signals are, however, highly spectrally efficient. For instance, the new IS-54 digital cellular signal standard has a roll-off of 0.35. Experiments show that a time-dependent filter placed at the output of a differential demodulator improves the performance of the IS-54 differential demodulator by over that of a conventional adaptive filter [Ree91a]. Results of the test cases using time-dependent filtering show a BER reduced by a factor of six and the MSE reduced by 9 dB over the time-independent filtering for signals distorted by Rayleigh fading. When a co-channel interfering signal is present, the time-dependent filtering process reduces the BER by a factor of two and the MSE by more than 5 dB over the time-independent filtered signal. In a similar test case, where interference was included, the BER improved by a factor of 100 when the interfering signal overlapped the signal-of-interest by 75% for a SIR of 6 dB.

C. Biographies of Principal Investigators

Theodore S. Rappaport

Theodore S. Rappaport is an associate professor at Virginia Tech and the founder of the Mobile and Portable Radio Research Group (MPRG). Under Dr. Rappaport's direction, the MPRG was formed in 1990 and has grown to include several faculty members, staff members, and over 30 graduate students. The MPRG is guided by 15 affiliated companies and government agencies which provide direction and funding to the group. The goals of the MPRG are to develop future engineers and technologies for the wireless industry and to transfer technology to affiliated companies and sponsors.

Professor Rappaport conducts research in mobile radio communications system design and RF propagation prediction through measurements and modeling. He has authored or co-authored more than 70 technical papers in the areas of mobile radio communications and propagation, vehicular navigation, ionospheric propagation, and wideband communications. He holds several patents for a wideband antenna and is co-inventor of SIRCIM, an indoor radio channel simulator that has been adopted by over 80 companies and universities. In 1990, he received the Marconi Young Scientist Award for his contributions in indoor radio communications and was named a National Science Foundation Presidential Faculty Fellow in 1992. He is a senior editor of the IEEE Journal on Selected Areas in Communication and Fellow of the Radio Club of America. Dr. Rappaport is a registered professional engineer in the state of Virginia.

Brian D. Woerner

Brian D. Woerner received his B.S. degree in computer and electrical engineering from Purdue University in 1986, and his M.S. and Ph.D. degrees from the University of Michigan, in 1987 and 1991 respectively, where he was a Unisys Fellow. Dr. Woerner has also earned a Master's degree in Public Policy from the University of Michigan with an emphasis on telecommunications policy. Since 1991, Dr. Woerner has worked as an Assistant Professor with the Bradley Department of Electrical Engineering at Virginia Tech in Blacksburg, VA. He is an active member of the MPRG. He has received a Research Initiation Award from the National Science Foundation and has been recognized for outstanding teaching. His research interests lie in the field of wireless communications, particularly in the analysis of modulation, error correction and code division multiple access techniques.

Jeffrey H. Reed

Jeffrey H. Reed is a member of the MPRG at Virginia Tech. His specialty is in applying digital signal processing to communication systems, and he has a particular interest in DSP techniques for interference rejection. Dr. Reed received his BSEE in 1979, MSEE in 1980, and Ph.D. in 1987, all from the University of California, Davis. He received the American Electronics Teaching Fellowship Award while completing his Ph.D. at the University of California, Davis. From 1980 to 1986, he worked for Signal Science, a small consulting firm specializing in DSP and communication systems. During 1982 he was stationed at the National Security Agency. After graduating with his Ph.D. degree, Dr. Reed worked as a private consultant and as a part-time faculty member at the University of California, Davis. In August, 1992, Dr. Reed joined the faculty of the Bradley Department of Electrical Engineering at Virginia Tech.

5. Management of Proposed Research

In this section we discuss the management of the proposed research, including a timetable and budget for Phase 1. The MPRG will be responsible for the conduct of the reset described in this proposal, with Drs. Woerner, Rappaport, and Reed serving as co-principal investigators. The MPRG will conduct the research independently, but will offer each of the major AVM service providers an opportunity to participate financially and technically in the study. Results will be reviewed by an independent consultant from another academic institution.

Timetable

Phase 1 of the proposed research will require nine months. The project is proposed to run from the period October 1, 1993 to June 30, 1994. The budget for the project reflects the fact that the majority of the work will be performed during the time period of October 1, 1993 to May 15, 1994. A timetable for Phase 1 is provided below.

TASK	*Months*								
	1	2	3	4	5	6	7	8	9
Task A - Definition of a Baseline AVM System	•								
Task B - Theoretical Baseline Analysis		•							
Task C - Analysis of RF Propagation Effects			•	•	•	•			
Task D - Evaluation of Interference Effects			•	•	•	•			
Task E - Limitations of Practical RF Systems							•		
Task F - Description of Candidate Spectrum Sharing Techniques								•	
Task G - Evaluation and Documentation of Results									•

Preliminary Budget

A preliminary budget for the proposal is included below. Dr. Woerner and Dr. Rappaport will manage Phase 1 of the project. Dr. Reed will be available for consulting and will participate in later phases of the project. A portion of time for MPRG administrator Jenny Frank and MPRG research associate Prab Koushik is included in the budget. The project will employ two graduate students to conduct the research under the direction of Dr. Rappaport and Dr. Woerner. A senior level graduate student will be employed as a Graduate Project Assistant and an M.S. student will be employed as a Graduate Research Assistant. Funds totalling $7500 are included for an independent consultant from

WINLAB to evaluate the work done at the MPRG. Since the work will require the use of computer resources for simulation and analysis, the project also includes $7500 for the acquisition of additional computer equipment. This equipment will remain the property of MPRG at the conclusion of the project. The total cost of the project is approximately $70,007.

Preliminary Budget

Faculty	Dates	Effort	Cost
B. Woerner	10/1/93-5/15/94	10% AY	4,122
J. Reed			0
T. Rappaport	10/1/93-5/15/94	5% AY	2,513
Staff			
J. Frank	10/1/93-5/15/94	5% CY	555
P. Koushik	10/1/93-5/15/94	5% CY	1,211
Fringe Benefits			2,167
Students			
1 GPA	10/1/93-5/15/94	100%	12,578
1 GRA	10/1/93-5/15/94	100%	9,075
Total Personnel Costs			32,221
Equipment	10/1/93-6/30/94		7,500
Travel	10/1/93-6/30/94		1,000
Consulting Subcontract	10/1/93-6/30/94		7,500
Total Direct Costs	10/1/93-6/30/94		48,221
Indirect Costs	10/1/93-6/30/94		21,786
Total Cost	10/1/93-6/30/94		$70,007

References

Age93 B.G. Agee, K. Cohen, J.H. Reed, T.C. Hsia, "Simulation Performance Of A Blind Adaptive Array For A Realistic Mobile Channel," *1993 Vehicular Technology Conference.*

Age93 B.G. Agee, K. Cohen, J.H. Reed, T.C. Hsia. "Simulation Performance Of a Blind Adaptive Array For a Realistic Mobile Channel," *1993 Vehicular Technology Conference*, May 1993.

Cam93a Rick Cameron, "Performance Analysis of CDMA Systems in Multipath Channels," *M.S. Thesis*, Virginia Polytechnic Institute and State University, May 1993.

Cam93b Rick Cameron and Brian D. Woerner, "An Analytic Technique for Performance Evaluation of a CDMA RAKE Receiver," *IEEE Vehicular Technology Conference* (VTC), Piscataway, NJ, May 1993.

Fer81 E. R. Ferrara and B. Widrow, "The Time-Sequenced Adaptive Filter," *IEEE Transactions on Acoustics, Speech, and Signal Processing*, Vol ASSP-29, June 1981, pp. 679-683.

Fun93 V. Fung, T.S. Rappaport, B. Thoma, Bit Error Simulation for Pi/4 DQPSK Mobile Radio Communications using Two-Ray and Measurement-Based Impulse Response Models," *IEEE Journal on Selected Areas in Communications*, JSAC Vo. 12, No. 4, April 93.

Ho93 C.M.P. Ho, "Antenna Effects on Indoor Wireless Channels and a Deterministic Wide-Band Propagation Model for In-Building Personal Communications Systems," *M.S. Thesis*, Virginia Polytechnic Institute and State University, Blacksburg, VA, April 1993.

Hol93 R. Holley, "CDMA Interference Rejection Using Time-Dependent Filtering," *M.S. Thesis*, Virginia Tech, December 1993.

Leh87 J. Lehnert and M. B. Pursley, "Error Probabilities for Binary Direct-Sequence Spread-Spectrum Communications with Random Signature Sequences," *IEEE Trans. on Comm.*, January 1987.

Leh89 J. S. Lehnert, "An Efficient Technique for Evaluating Direct-Sequence Spread-Spectrum Multiple-Access Communications," *IEEE Trans. on Comm.*, vol. 37, no. 8, pp. 851-858, August 1989

Li93a Yingjie Li, Brian D. Woerner, William Tanis II, and Mike Hughes, "Simulation of CDMA Using Measured Channel Impulse Response Data," *IEEE Vehicular Technology Conference* (VTC), Piscataway, NJ, May 1993.

Li93b Yingjie Li, "Bit Error Rate Simulation of 1.25 MHz CDMA Simulations," *M.S. Thesis*, Virginia Polytechnic Institute and State University, July 1993.

Men89 R. Mendoza, J. H. Reed, and T.C. Hsia, "Interference Rejection Using a Hybrid Constant Modulus Algorithm and Spectral Correlation Discriminator," *1989 IEEE Military Communications Conference Proceedings*, Boston, October 1989.

Men91 R. Mendoza, J. H. Reed, T. C. Hsia, and B. G. Agee. "Interference Rejection Using the Generalized Constant Modulus Algorithm and the Hybrid CMA/SCD," *IEEE Transactions on Acoustics, Speech and Signal Processing*, September 1991.

Rap90 T.S. Rappaport, S.Y. Seidel, "SIRCIM: Simulation of Indoor Radio Channel Impulse Response Models," 1990, VTIP, Inc.

Rap91 T.S. Rappaport, "A Thumbnail Sketch of the Past, Present, and Future of Wireless Personal Communications," report for Dr. Lancer Glasser, Program Manager, DARPA, Oct. 1991.

Rap91a T. S. Rappaport, V. Fung, "Simulation of bit error performance of FSK, BPSK, and $\pi/4$ DQPSK in flat fading indoor radio channels using a measurement-based channel model," *IEEE Trans. Veh. Tech.*, Vol. VT-40, No. 4, pp. 731-741, Nov. 1991.

Rap91b T.S. Rappaport, S.Y. Seidel, and K. Takamizawa, "Statistical Channel Impulse Response Models for Factory and Open Plan Building Radio Communication System Design," *IEEE Trans. on Comm.*, vol. COM-39, no. 6, pp. 794-797, June 1991.

Rap92 L. B. Milstein, T. S. Rappaport, and R. Barghouti, "Performance Evaluation for Cellular CDMA," *IEEE Journal on Selected Areas in Comm.*, vol. 10, no. 4, pp. 680-689, September 1992.

Ree87 J. H. Reed, *Time-Dependent Adaptive Filters for Interference Rejection, Ph.D. Dissertation*, Department of Electrical and Computer Engineering, University of California, Davis, 1987.

Ree88 J. H. Reed and T. C. Hsia, "A Technique for Sorting and Detecting Signals in Interference," *1988 IEEE Military Communications Conference Proceedings*, San Diego, October 1988.

Ree89 J. H. Reed, C. D. Greene, and T. C. Hsia. "Demodulation Of A Direct Sequence Spread-Spectrum Signal Using An Optimal Time-Dependent Receiver," *1989 IEEE Military Communications Conference*, Boston, October 1989.

Ree90a J. H. Reed and T. C. Hsia, "The Theoretical Performance Of Time-Dependent Adaptive Filters For Interference Rejection," *1990 IEEE Military Communications Conference*, October 1990, pp. 47.2.1-47.2.5.

Ree91a J.H. Reed and R.J. Kleinman, *An Optimal Time-Dependent Receiver for Interference Rejection and Its Application to the New North American Digital Cellular Telephone Standard*, Final Report, ISI-9060106, September 1991.

Ree91b J. H. Reed and T. C. Hsia, "The Performance Of Time-Dependent Optimal Filtering For Interference Rejection," *IEEE Transactions on Signal Processing*, August 1990, pp. 1373-1385.

Ree92 J.Reed and B.G. Agee, "A Maximum-Likelihood Approach To Detecting Frequency Hopping Spread Spectrum Signals," *1992 Asilomar Conference on Signals, Systems, and Computers*.

Sei92a S.Y. Seidel, "Site-Specific Propagation Prediction for Wireless In-Building Personal Communication System Design," MPRG-TR-92-07, February 1992.

Sei92b S.Y. Seidel, et. al, "The Impact of Surrounding Buildings on Propagation for Wireless In-Building Personal Communications System Design," *42nd IEEE Vehicular Technology Conference*, Denver, CO, May 1992.

Sei93 S. Y. Seidel, "Site-Specific Propagation Prediction for Wireless In-Building Personal Communication Systems Design," *Ph.D. Dissertation*, Virginia Polytechnic Institute and State University, Blacksburg, VA, February 1993.

Tho92 B. Thoma, "Bit Error Rate Simulation Enhancement and Outage Prediction in Mobile Communication Systems," *M.S. Thesis*, Virginia Polytechnic Institute and State University, July 1992.

Tra93 T. T. Tran, "Propagation Prediction for PCS Design in Urban Microwave Channels," *M.S. Thesis*, Virginia Polytechnic Institute and State University, Blacksburg, VA, April 1993.

Woe91 B. D. Woerner, "Coded Modulation for Direct-Sequence Spread-Spectrum Communications," *Ph.D. Thesis*, University of Michigan, 1991.

Woe92a Brian D. Woerner and Rick Cameron, "An Analysis of CDMA with Imperfect Power Control," *IEEE Vehicular Technology Conference* (VTC), Denver, CO, May 1992.

Woe92b B. D. Woerner and Wayne E. Stark, "Trellis coding for direct-sequence spread-spectrum communications," *IEEE Transactions on Communications*, accepted for publication.

Woe92b Brian D. Woerner, "Optimum Code Rates for Packet CDMA Communications Systems," *Proceedings of the WINLAB Workshop on 3rd Generation Wireless Communication Systems*, April 1992.